Improved Techniques for Targeting Additional Observations to Improve Forecast Skill

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Grant Number: N00014–99–1–0755

LONG-TERM GOAL

This project aims to improve weather forecasts using adaptive observation techniques based on targeted singular vector analysis with a particular focus on severe weather events in the tropics and extra-tropics in the range 0–5 days.

OBJECTIVES

It will be addressed how sensitive the leading singular vectors used for observation targeting are to the choice of norm and the approximations made in the tangent-linear model. It is investigated how to extend the singular vector based observation targeting by a step that provides a measure of the statistically expected impact that a particular set of supplementary observations will have on a future forecast. The main objective of this extension of the singular vector approach is to provide guidance concerning decisions about suitable spatial sampling patterns and a suitable choice of observation types for the adaptive observing network upgrade. It is envisaged to use the improved singular vector technique as a real-time planning tool in a targeted observation experiment and to evaluate its predictive skill.

APPROACH

Information about the distribution of initial errors is obtained from the Hessian of the cost function of a variational assimilation scheme. The estimate of initial condition uncertainty provided by the Hessian is consistent with the statistical assumptions that underlie the assimilation scheme. Information about changes of the initial condition uncertainty are obtained from the Hessian of a modified cost function that contains a term for the supplementary observations in addition to the term for the routine observing network.

Tim Palmer is managing the overall development of the ECMWF ensemble prediction system. Jan

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Improved Techniques for Targeting Additional Observations to Improve Forecast Skill**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Meteo' France CNRM/GMME/RECYF,42 av. G. Coriolis 31057 ,Toulouse cedex 1,France, , ,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This project aims to improve weather forecasts using adaptive observation techniques based on targeted singular vector analysis with a particular focus on severe weather events in the tropics and extra-tropics in the range 0-5 days.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Barkmeijer has worked on optimal perturbations of the tendencies, so-called forcing singular vectors. At Météo-France, Martin Leutbecher is evaluating the impact of targeted observations and working on the singular vector based estimate of forecast error variance changes due to targeted observations. Thierry Bergot and Alex Doerenbecher have developed a different approach of taking the data assimilation scheme into account in an adaptive observation strategy. Gwenaëlle Hello studies whether the background error covariance estimate used in the assimilation scheme can be adjusted locally to improve the impact of the existing data. Furthermore, Philippe Arbogast and a group of forecasters tested a simple way to modify the forecast in the direction of a sensitivity field (following Hello et al. 2000) throughout the cold season.

WORK COMPLETED

Additional experiments were performed for the storm that crossed France and Germany on 26 December 1999 in order to compare the impact of future generation satellite radiance data with the impact of *in situ* observations of wind and temperature.

A reduced rank estimate of forecast error variance changes due to the addition or removal of data during one assimilation cycle has been developed. We refer to it as Hessian reduced rank estimate as it is based on the Hessian of the cost function of a variational assimilation scheme.

RESULTS

The Hessian reduced rank estimate (HRR, Leutbecher 2002) of forecast error variance is an attempt to approximate the predictions of forecast error variance that could be obtained with an extended Kalman filter. Changes of forecast error variance due to a modification of the observing network are evaluated in a subspace spanned by the leading n Hessian singular vectors computed for the routine observing network. Via a projection of forecast errors on the singular vector subspace the rank of the problem is reduced and thus the computations become feasible even for operational numerical weather prediction systems.

From a theoretical point of view, the HRR is closely related to the Ensemble Transform Kalman Filter technique (ETKF, Bishop et al. 2001). The HRR can be interpreted as an application of the ETKF to a set of Hessian singular vectors. Its potential advantage over the ETKF applied to a set of evolved ensemble perturbations is that it is consistent with the statistics of an operational variational assimilation scheme. The Kalman Filter Sensitivity (KFS, Bergot and Doerenbecher 2002) and the observation sensitivity are so far the only other technique that achieves consistency with an operational variational assimilation scheme. The KFS determines the change of variance in one direction of phase space. The HRR generalizes this idea; it quantifies the change of variance in n directions given by the leading singular vectors. The dimension n can be adapted to the type of forecast problem of interest.

Several hypothetical options to adapt the observing network in order to improve the 48-hour forecast of the French/German storm of 26 December 1999 have been examined with the HRR. Here two examples are given, see Leutbecher (2002) for a full description. A significant reduction of the expected total energy of the projected forecast error is predicted if the supplementary observations are placed in a target region diagnosed from the singular vectors (Exp. c, Fig. 1a) but not if they are remote from this target region (Exp. b, Fig 1a). An idealized comparison of the impact of targeted *in situ* observations (Exp. g) with the impact of “future generation satellite radiance data” covering a much wider region (Exp. m) is plotted in Fig. 1b. The expected reduction r_n of the total energy of the forecast error is normalized with the expected total energy ε_n of the forecast error associated with the routine observing network (ε_n corresponds to the solid curve in Fig. 1a). The prediction depends in an interesting way on the dimension n of the subspace of leading singular vectors on which the forecast error is projected. For a dimension greater than three the “satellite data” are superior. The experiment yields an upper bound of the impact that could be achieved with satellite radiances because it has been assumed that temperature profiles with the accuracy and vertical resolution of radiosondes can be retrieved from the radiance data and because the presence of cloud was ignored.

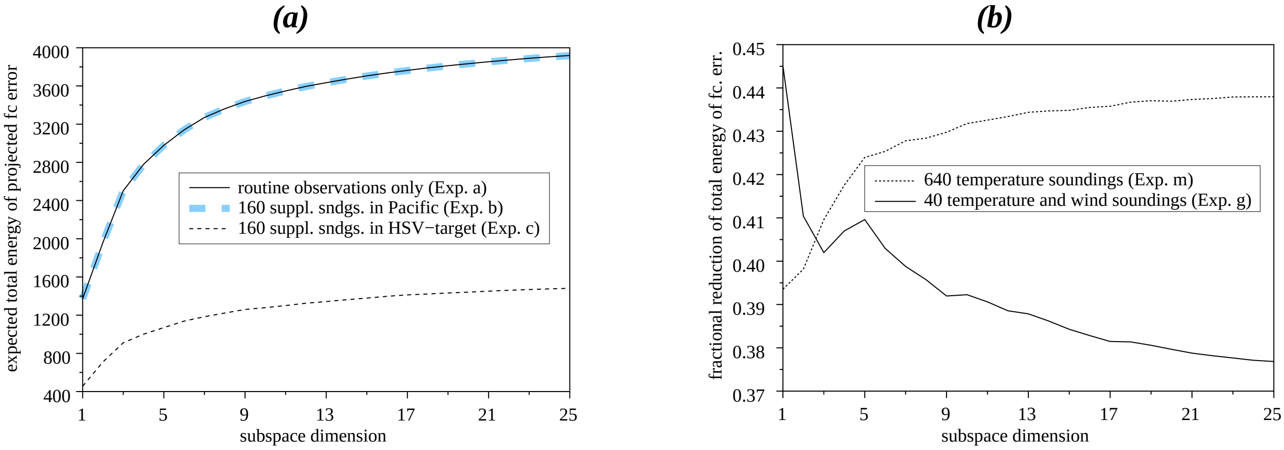

Fig. 1: (a) Expectation value of total energy of projected forecast error versus subspace dimension n for three different observing networks. (b) Fractional reduction of the total energy of forecast error r_n/ε_n versus subspace dimension n for two network upgrades that differ in terms of observation type.

Clouds limit the spatial coverage of satellite radiance data that are useful for numerical weather prediction. A set of analysis/forecast experiments has been performed for the French/German storm of 26 December 1999 to quantify how the limited coverage due to clouds in the sensitive region affects the potential of satellite radiance data to constrain the forecast error. Future satellite radiance observations may contain significantly more useful information than data coming from current satellites. To obtain an upper bound of the potential forecast improvement due to the utilization of next generation satellite radiances, the assimilation of such data was represented by using temperature profiles with the accuracy and vertical resolution of a radiosonde. However, it is envisaged to perform additional experiments using the observation operators of advanced multispectral sounders such as IASI (Infrared Atmospheric Sounding Interferometer). In order to be able to use such radiance observation operators a recent version of the ECMWF forecast model with a model top at 0.1 hPa was used. As a result of the change of the model version the cyclone in the truth experiment is less deep (974 hPa) than in the original experiment (968 hPa) presented by Leutbecher et al. (2002). Apart from this, the truth and control are quite similar to the original experiments.

Figure 2 shows the effective cloudiness at 40 sounding locations targeted with singular vectors. It is assumed that it is likely to find a cloud free pixel on the scale of the model grid if the total cloud cover predicted by the ECMWF model is below 0.7. Such locations are labelled as effectively cloud-free. Similarly, an effective cloud top height is diagnosed as the highest level where the cloud cover accumulated from the top of the atmosphere exceeds 0.7. Table 1 summarizes the analysis/forecast

Exp.	size	N_{snd}	N_{obs}	data	R_{TE}	R_{PC}
S1	S	40	2640	wind and temperature	0.58	0.6
S2	S	40	880	temperature	0.48	0.6
S3	S	9	198	temperature at cloud-free spots	0.29	0.4
L1	L	160	3520	temperature	0.66	0.9
L2	L	74	1628	temperature at cloud-free spots	0.39	0.7
L3	L	138[a]	2342	temperature 100 hPa above cloud-top	0.42	0.8

(a) 74 effectively cloud-free spots plus 64 cloudy sounding locations, with effective cloud top height below 300 hPa

N_{snd}: number of soundings; N_{obs}: number of observations

R_{TE} : reduction of the total energy of the 48-hour forecast error in the verification region (35°–60°N, 20°W–20°E), normalized with the error of the control experiment

R_{PC} : reduction of the 48-hour forecast error of the central pressure of the cyclone, normalized with the error of the control experiment (10 hPa).

Tab. 1: Summary of Analysis/forecast experiments.

experiments. A "small" (S:13×10^6 km^2) target region and a large (L:50×10^6 km^2) one are considered. Experiment S1, which uses 40 dropsondes in target S, serves as reference. If temperature profiles in the entire target L are assimilated (Exp. L1), the reduction of forecast error is larger than in Exp. S1 both in terms of the total energy metric in the verification region and in terms of the central pressure of the cyclone. In target S, only 9 of 40 sounding locations are effectively cloud-free. Despite the very limited coverage, a significant reduction of forecast error can be achieved with these 9 temperature profiles in particular in terms of deepening the cyclone (Exp. S3). In target L, 74 of 160 sounding locations are effectively cloud-free. These 74 temperature profiles yield a reduction of the central pressure error by 7 hPa (Exp. L2) compared to 6 hPa in Exp. S1. However, in terms of the total energy of the forecast error none of the Exps. S3, L2, and L3, which use temperature profiles only at locations were satellite radiances might provide useful information, has a smaller forecast error than the reference Exp. S1.

The forecast improvement obtained by using temperature profiles at effectively cloud-free locations may be fortuitous in this case and related to the particular realization of initial error. Furthermore, real satellite radiances are expected to exhibit observation errors with significant spatial correlations unlike radiosonde data. The spatial error correlations are difficult to quantify and difficult to account for in the assimilation. The results shown here yield a very optimistic estimate of the impact of satellite data as no attempt has been made to account for realistic observation errors in the simulated observations.

IMPACT/APPLICATIONS

Further work is required to develop prognostic versions of the HRR and the KFS techniques that are suitable for real-time applications. Thereafter, a parallel evaluation of the predictions of these adjoint-based techniques and the predictions of the ETKF as implemented at NCEP could be envisaged.

RELATED PROJECTS

The techniques described in this report could be utilised in the proposed THORpex experiment.

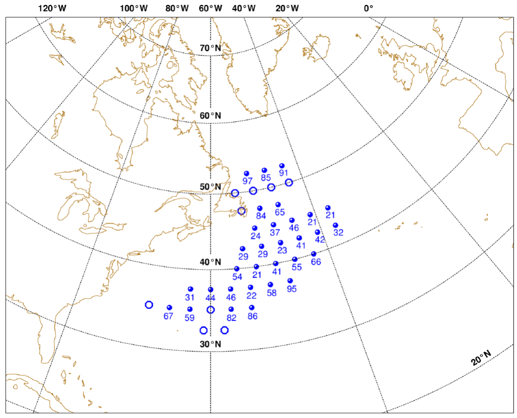

Fig. 2: Sounding locations in target S. Open circles: effectively cloud free spots, filled dots: cloudy locations with effective cloud top pressure in kPa.

SUMMARY

A technique has been proposed to evaluated changes of forecast error variance due to a modification of the observing network in a subspace of leading Hessian singular vectors. It has been shown that this technique is theoretically equivalent to an application of the ensemble transform Kalman filter technique to the set of leading Hessian singular vectors. Furthermore, the close relationship of this technique and the Kalman filter sensitivity has been elaborated.

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